



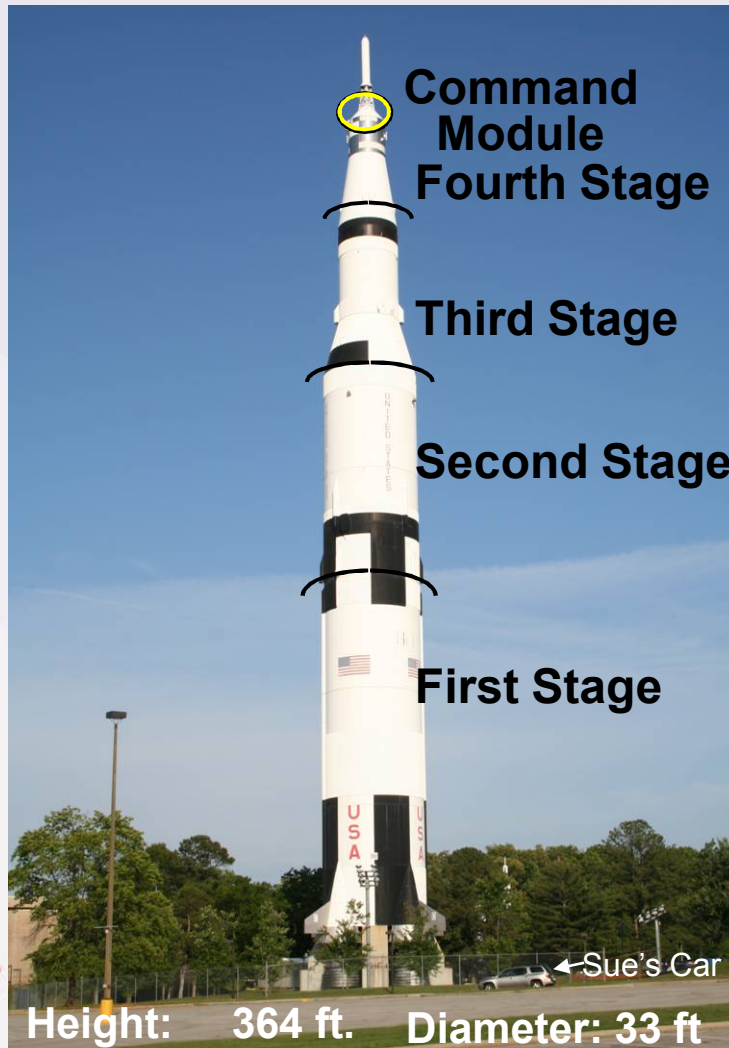
Progress of the NASA/USGS Lunar Regolith Simulant Project

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SATURN V



	Weight (lbs.)	Altitude (miles)	Velocity (mph)
Command Module	12,807		
Service Module	54,064		
Lunar Module	32,299		
Trans Lunar Burn	265,000	239,000	24,500
Orbital Burn		115	17,500
	1,037,000	114	15,300
	4,881,000	38	6,000
	<u>6,600,000</u>		





Project Development

Beginning in 2004 personnel at MSFC began serious efforts to develop a new generation of lunar simulants. The first two products were a replication of the previous JSC-1 simulant under a contract to Orbitec and a major workshop in 2005 on future simulant development.

It was recognized in early 2006 there were serious limitations with the standard approach of simply taking a single terrestrial rock and grinding it. To a geologist, even a cursory examination of the Lunar Sourcebook shows that matching lunar heterogeneity, crystal size, relative mineral abundances, lack of H₂O, plagioclase chemistry and glass abundance simply can not be done with any simple combination of terrestrial rocks.

Thus the project refocused its efforts and approached simulant development in a new and more comprehensive manner, examining new approaches in simulant development and ways to more accurately compare simulants to actual lunar materials. This led to a multi-year effort with five major tasks running in parallel.

The five tasks are Requirements, Lunar Analysis, Process Development, Feed Stocks, and Standards.



Requirements

In many respects this is a science project meeting an engineering goal. We must work against written, objective requirements.

A substantial draft of a formal requirements document now exists and has been largely stable since 2007. It evolves as specific details of the standards and Lunar Analysis efforts proceed.

It defines terminology, incidental aspects such as handling, and states how simulants are to be evaluated.

All the properties are expressed as attributes of large collections of particles.



Requirements 2

There are four components, each of which contains multiple measurements for a complete description. Note that each measurement can also stand alone.

- Particle type
- Size distribution – Exactly what this means has been defined with much help from Allen Wilkinson/GRC and others. Large collection of existing data
~5 μ m – 1cm.
- Shape Distribution – recent development Phil Metzger/KSC will perform our shape measurements
- Density – Exactly what this means has been defined with much help from Allen Wilkinson/GRC and others. We do not have a lab committed to providing these values on a continuous basis.



Requirements 3

Changes since first

- Solid Solutions
- Glass
- Lithic Fragments
- Contaminants

Not covered –

- Magnetism
- Reflection/absorption/transmission/emission spectra
- Vapor deposited rims
- Strength of particles



Standards have been a major success for the project. The Figure of Merit (FoM) algorithms have been created, tested, and are being considered for an ISO standard (Fred Slane). Agreement has been reached in the community about how to make many of the critical measurements.

The standard does not measure all properties, rather it assumes that if certain properties (primary) are constrained all other (derivative) properties will also be constrained.

Long list of characteristics must be met for a property to be useful for this purpose. For example it must be

- knowable for the lunar material
- reproducibly measurable
- non-redundant
- discriminating

The mathematics of the the FoM were done by Hans Hoelzer/TBE, who also lead the algorithm coding.

A property has a value between 0 – 1. 1 closely matches the reference material.

There is no other process known which permits standardized comparison of complex mixtures of particles.



Lunar Analysis

Lunar Analysis has turned out to be vastly more difficult than anticipated.

After great effort to mine existing published and gray literature, the team has realized the necessity of making new measurements of the Apollo samples, an effort that is currently in progress.

The requirement is to know a full set of properties about a specific sample, which is physically and aggregate. The very small particle size of the regolith makes this a major technical problem.

We learned a huge amount working with Intellection of Australia, Alan Butcher and Pieter Botha.

We have received permission to analyze thin sections of lunar regolith. This is currently on going at the USGS by Doug Stoesser & Greg Meeker.



Process Development

Process development is substantially ahead of expectations in 2006. This is largely due to Steve Wilson/USGS.

- It is now practical to synthesize glasses of appropriate composition and purity (Zybek) 100 kg/hour
- It is practical to synthesize agglutinate particles (Orbitec) kg/hour
- Developing processes to make agglutinate particles in significant quantities. (Orbitec and now Orbitec & Zybek)
- A series of minerals commonly found on the Moon has been synthesized. (Zybek)
- Synthesized breccia (Zybek)

Separation of mineral constituents from starting rock material is also proceeding.

Customized grinding and mixing processes have been developed and tested are now being documented.



Process Development 2

NU-LHT-1M, NU-LHT-2M, NU-LHT-2C, NU-LHT-1D have been produced.

Considering mare and ilmenite rich prototypes.

Major interest in driving cost per ton down.

Also considering how to produce simulants in 100 – 1000 ton lots for some engineering applications.

Commercial players

- EVC/NORCAT / Sudbury, On – Jim Richard
- Orbitec / Madison, WI – Bob Gustafson
- Zybek / Boulder, CO – Mike Weinstein
- Others – non-US and US



This has been led by Doug Stoesser/USGS

Identification and development of appropriate feedstocks has been both easier and more difficult than anticipated.

The Stillwater Mining Company, operating in the Stillwater layered mafic intrusive complex of Montana, has been an amazing resource for the project. The company has been extremely generous about helping us.

This is really a problem in industrial minerals. The quantities involved require permitted land. The resource has to sustain production at the rate of 100-1000 tons/year. Even in prototyping we are using 10 tons/year.

Finding adequate sources for some of the components remains a difficult problem. For example the ratio of clino- to ortho-pyroxenes in the Stillwater is not an exact match for lunar materials. One of the sources being examined as an alternative pyroxene source is the Bushveld Complex in South Africa.

Some of the material can be bought: pyrite, apatite, olivine, whitlockite, spinel.



Other Activities

Chemistry

Toxicology

DTA, TGA, Mass spec

Working on a book



There remains much work to do:

- (1) driving down the cost of simulants remains a major obstacle;
- (2) documentation and cost data analysis have not kept up with progress;
- (3) educating users in the complexity of the lunar regolith and the use of simulants remains a major task.

In summary the project has made enormous progress and is successfully placing simulant development and use on a rigorous, scientifically defensible, engineering basis.

